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ABSTRACT

The scalar electrocardiogram (ECG) is one of the most important and commonly used clinical tools in medicine. A detailed description of the recordings of cardiac electrical activity made by the ECG is presented, and the vast numbers of uses made with the data provided by this diagnostic tool are cited. Clinical applications of the ECG are listed. More emphasis is placed on the fact that advances in the biomedical engineering aspects of clinical electrocardiography will require improved and on-going communication between the engineer and the clinician. (Author/EB)

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CLINICAL APPLICATION OF FLECTROCARDIOGRAPHY

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The standard scalar electrocardiogram (ECG) is composed of 12 to 14 separate recordings of cardiac electrical activity: each one from a distinct electrode configuration (lead). This tracing is one of the more frequently requested laboratory tests in clinical medicine. Thousands of these examinations are done daily not only on patients with known or suspected cardiovascular disease but on patients for whom screening or clearance is desired, e.g. prior to elective surgery, entry into a physical conditioning program, or as part of a routine evaluation. For patients with cardiovascular disease the ECG is a necessary part of any evaluation and changes that occur in the ECG over time may be an important indicator of improvement, deterioration, or impending difficulty. As necessary as the ECG is to good patient evaluation and clinical problem-solving, it is but one of several pieces of information that is required for an accurate and rational clinical diagnosis. The other parts of the cardiovascular evaluation include a careful history and physical examination, a chest x-ray, and special procedures indicated by the information obtained from the basic evaluation techniques. Special procedures such as cardiac catheterization, exercise stress testing, certain blood studies or long term ambulatory monitoring might be indicated.

Many clinicians tend to think of the ECG as a precise diagnostic tool; only occasionally is this so. Some rhythm abnormalities and the presence of heart damage may be accurately detected, but most often the ECG provides clues that might lead to a specific diagnosis

or shows quite non-specific abnormalities. The electrocardiogram is rarely diagnostically precise.

Four elements are required if the ECG's clinical usefulness is to be optimized. First, the recording device must have suitable characteristics providing the appropriate frequency response, a stable paper speed, and must be equipped with simple maintenance checks so that machine performance can easily be evaluated. Second, electrodes must be properly positioned and the recording must be of good technical quality. Third, appropriately detailed information regarding each specific patient must be recorded. Fourth, if the goal of assisting in patient care is to be achieved, the information from the ECG tracing must be integrated with the specific knowledge regarding the patient and an optimal interpretation of the electrocardiogram must be made. At the present time, it would appear that well-trained cardiologists are capable of an acceptable interpretive performance, but that the computer will be able to greatly enhance the capability of the cardiologist through the application of techniques too complex, laborious, and time-consuming to otherwise be considered.

In a single ECG lead, some more than others, can be found useful information regarding heart rate, rhythm, hypertrophy of any one of the four cardiac chambers, conduction time from the atria to the ventricles, conduction time through the ventricles, specific abnormalities of the conduction system of the heart, and the presence of

myocardial injury, ischemia or damage. In addition, a lead may suggest specific metabolic or electrolyte abnormalities, and at times may suggest the presence of important disease in other body systems -- for example, the lungs and occasionally the central nervous system.

The electrocardiographic complex is made up of several wave forms (Figure 1).

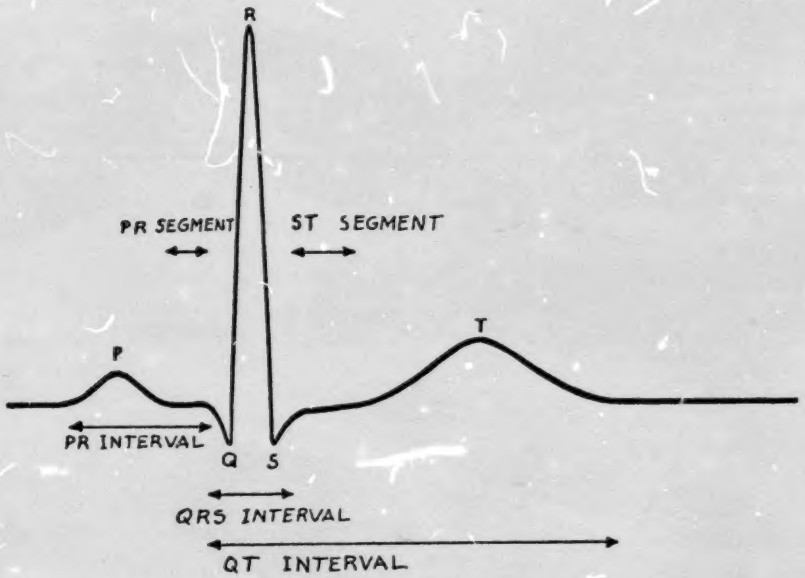

Figure 1. The Normal ECG Complex. (See text for details.)

The P wave represents atrial depolarization. The PR segment reflects the time from initial atrial depolarization until the electrical activity reaches the ventricles and generates the QRS complex which represents ventricular depolarization. The ST segment and T wave are inscribed during ventricular repolarization or recovery.

Examination of all portions of the complex may suggest important clinical events which may in turn lead to a correct diagnosis and appropriate management. The height, duration and shape of the P wave in certain leads may reflect enlargement of the right or left atrium, or that the heart is being commanded from an abnormal atrial site. Alterations in the duration of atrio-ventricular conduction, as reflected in the PR segment, may be the result of drug effects, heart block rhythms (due to a variety of causes), normal variants, or abnormal conduction pathways from the atria to the ventricles bypassing the normal conduction route. The QRS complex must be examined carefully. The initial 0.04 seconds reflects myocardial damage if present. The direction of the terminal 0.04 second electrical activity indicates the presence or absence of specific intraventricular conduction problems or may reflect (in the proper clinical setting) acute stress of the right ventricle. The magnitude and direction of the mean QRS vector in at least two planes are noted and reflect the presence or absence of enlargement of the right or left ventricle. ST segment and T wave abnormalities may indicate the presence of potentially reversible inadequate oxygen supply to a portion of the heart muscle but such changes are commonly non-specific and may be produced by eating, anxiety, a change in body position, certain drugs, or volume or pressure loads on the left ventricle. In addition, the ST segment and T wave, PR interval, P wave, and QRS complex may be significantly altered by metabolic and electrolyte

abnormalities. It is necessary, then, to study each portion of the ECG complex carefully, to integrate that information with what is learned from other portions of the complex, and finally to relate that information to the patient from whom the recording was made.

At the present time, common clinical applications of the electrocardiogram include:

1. A screening device for disease detection and disease prevention programs.
2. Monitoring the acutely ill patient.
3. Monitoring a patient undergoing a stress test.
4. Following the natural history of a disease.
5. Diagnosing a specific abnormality of cardiac rhythm.
6. Detecting and following the natural history of myocardial damage.
7. An adjunct in detecting and following metabolic and electrolyte abnormalities.

Some of these uses require a single lead only, others multiple leads. Regardless of the reason for which the electrocardiogram is obtained, accurate interpretation of the electrocardiogram is virtually impossible if at least some key patient characteristics are not known: age, height, weight, body build, body position during recording of the electrocardiogram, time from eating to recording of the tracing, relationship of the tracing to the last cigarette smoked, the patient's emotional state, drugs taken by the patient, the time the drugs were taken in relation to the recording of the electrocardiogram, the

underlying disease or diseases, the individual's metabolic status, and position of the ECG leads on the patient. Each patient is a multivariate object, and each ECG is a result of the total effect of the variables. Recent work by Pipberger et al[1] has shown that when a multivariate approach to the computer application of the standard ECG is used, the diagnostic accuracy of the computer exceeds that of a well trained cardiologist as well as other available computer programs which are programed to observe and integrate standard criteria in a decision-tree fashion.

Although the study of one lead may give much useful information, it is important to recognize that no single ECG lead gives all of the available useful information. For example, left atrial enlargement is not diagnosed by frontal plane lead aVR, and inferior myocardial damage is not reflected in standard lead I. For common clinical purposes, twelve leads are recorded. Standard leads I, II, III, aVR, aVL and aVF reflect activity in the frontal plane, that is, parallel to the anterior chest wall, and perpendicular to the floor. The precordial leads V_1 through V_6 record electrical activity in the horizontal plane, parallel to the floor, and perpendicular to the frontal plane. Usually, in order to make many electrocardiographic diagnoses, combinations of leads are required very often from both frontal and horizontal planes. Whether this will still be necessary in future years is uncertain. Clinical research utilizing the three

mutually perpendicular orthogonal leads X, Y, and Z recorded in scalar fashion is underway, and all useful clinical information may ultimately be available from these three leads.

It should be apparent from the preceding discussion that advances in the biomedical engineering aspects of clinical electrocardiography will require improved and on-going communication between the engineer and the clinician. This is not always easy to accomplish. Each speaks a different professional language, and all too often neither has a clear understanding of the needs or capabilities of the other. Clinicians are more likely to recognize that the human organism does not lend itself well to controls, and are therefore more tolerant of variation in outcome from research programs than is one trained in the physical sciences. The clinician also tends to guage the performance of engineering equipment or programs by conventional standards when actually the storage capability and speed of a computer permit improved outcome from ECG analysis provided the proper variables are programed into the machine. In other words, the standards of performance should not be those standards or guidelines which the clinician has used for many years. New, more complex multivariate approaches must be sought which should improve upon old diagnostic standards. In addition, the clinician does not, and often cannot tell the engineer precisely the information, display, or ultimate outcome desired from a specific bioengineering program. In

order to achieve an end product that is of clinical practicability and application, the clinician and engineer must communicate through all stages of the project -- planning, construction, and clinical trial -- and each must be willing to make appropriate modifications throughout. Both clinician and engineer must recognize that the final goal of the combined effort is to benefit a patient. This may require program or instrumentation modifications that at times offend the sensibilities of either investigator; however, if a patient is not ultimately well served, then the total effort is without clinical merit.

One of the greatest problems in the development of clinically useful programs using the ECG is the presentation of data. There are many ways that the engineer can handle the ECG wave forms. Contemporary computers can handle large volumes of data rapidly and reliably, but too often the presentation of the data is more meaningful to the engineer than it is to the clinician. The data must be clearly presented so that it is readily understood and directly applicable to patient care. A pictorial representation of the data is best. In this regard, the engineer needs to think like a clinician, since the practicing physician or staff nurse has little time to figure out a complex plot or presentation. Indeed, many data presentations will be seen more often by nursing personnel who will be responsible for the first and perhaps most important decisions regarding patient care.

Because all patients are different it may be desirable to develop computer programs for handling the electrocardiogram that can be readily modified to provide information regarding a specific and particular clinical situation. For example, in an arrhythmia detection program some patients will have a very narrow coupling interval of their ectopic beats to the normal complexes, others will have a very long coupling interval, almost as long as the normal R-R interval. In the latter instance an arrhythmia detection program designed to include only those beats that represent a change in R-R interval of 25% or more may not be detected. Looking at the specific wave form may be useful, but nevertheless the computer would not record these as premature beats when indeed they are.

Development of the human engineering aspects of biomedical engineering is one of the most important and one of the most difficult tasks. Very often a clinician does not know precisely what he wants to see and trial and error in the actual clinical situation is often necessary. It seems most appropriate if the information which is presented to the clinician is presented for clinical interpretation and action without providing a dogmatic diagnosis or single management outline. It is acceptable to give diagnostic probabilities and therapeutic options, but the responsibility for interpretation and action in the patient's behalf must remain with the clinician.

In summary, the scalar electrocardiogram is one of the most important and commonly used clinical tools in medicine. The opportunities for the biomedical engineer and the clinician to work together in this area are vast. Many strides have been made in this area already. Further work will require improved communication between the clinician and the engineer with good patient care being the ultimate goal of each.

Reference

[1] Pipberger, Hubert V.; McCaughan, Donald; Littmann, David; et al. Clinical Application of a Second Generation Electrocardiographic Computer Program. American Journal of Cardiology 35: 597-608, 1975